ENHANCED 3D-SPACE-SCANNING SYSTEM BY ROBOTIC TECHNOLOGY

Extracting Building Geometry and Capturing Human Behavior for Architectural Design

SHOUTO IWATA¹, MIKIYA TAKEI² and SHIRO MATSUSHIMA³
¹,²,³ Toyohashi University of Technology, Toyohashi, Japan
1. s095602@edu.imc.tut.ac.jp, 2. mu.ku.inclusive@gmail.com, 3. shirom@ace.tut.ac.jp

Abstract. This study, which scans an architectural space with two-wheeled vehicle robot technology that allows the flexible collection of three-dimensional (3D) data, may initiate the interaction between human beings and architecture in the future. It focuses on extracting building geometry and capturing human behavior in order to allow a space to communicate with human behavior. The current project extracts building geometry and human behavior data to create designs through a two-wheel robot; it was a collaborative project among the students of different majors, including mechanical engineering, human interaction, computer sciences, and architectural design. In this paper, the adaptive possibility of the RGB-Depth camera is examined in extracting building geometry.

Keywords. human behavior; robot; design process; scan.

1. Introduction

This paper proposes a mobile three-dimensional (3D) scanning system method that uses the robotics technology to obtain simultaneously a human behavior and building geometry. Architecture sometimes changes to adapt to human lifestyles through renovation or conversion. Recently, dynamic architecture, such as so-called "kinetic architecture," has proposed flexible solutions by responding to changing environmental conditions. In such cases, it is necessary to grasp information of situation and an environment. The conventional method for apprehending them relies on the accumulation of static moments of the interaction between architecture and human beings. Howev-
er, several technologies make it easier and cheaper to obtain building geometry and human behavior. For example, the 3D scan system extracts an existing building in the renovation of design. Human tracking systems, such as the Microsoft Kinect range of game controllers, also extends the possibility of applying human behavior to interactive design in real-time. Such technology will become indispensable for the alternative architectural design process that includes design change with the time lapses of ordinary life.

This paper examines adaptive possibility of RGB-Depth camera to extract building geometry; it is organized into five sections; first, it discusses the drawbacks of conventional methods of capturing human motion and extracting building geometry. Second, the paper describes an experiment for extracting building geometry and human behavior. Third, it describes the design process of robot development and human tracking technology. Fourth, we propose the design method for bring together a robot and human behavior. Finally, the effectiveness of this design method and the possible applications of robotics technologies in architectural design with robots and scanning systems are discussed.

2. Literature review

2.1. EXTRACTING BUILDING GEOMETRY

An architectural field generally uses a 3D scan system that captures shapes as point cloud data radially. Hajian and Becerik-Gerber have created as-built 3D Computer-Aided Designs (CAD) or Building Information Models (BIM) of existing facilities and new construction. Furthermore, Fujii et al. shows example of renovation works with 3D laser scanner and 3D CAD System for Pre-Cut manufacturing. However, normal 3D scanning processes present problems: measuring from only a single point generates dead angles, and if dynamic objects exist in the measuring range, they are captured as static objects.

In contrast, in fields other than architecture, many people (Yue et al., 2007; Furukawa et al., 2011) have tried to extract building geometry. For example, many robots are equipped with a laser range finder that has a very high accuracy; however, it can only normally obtain planar data. From the standpoint of architectural design, it is insufficient to understand the building geometry.

To solve these problems, Huang et al. (2011) have attempted to use a RGB-Depth camera on a quadrocopter. This project shows the advantages of applying mobile robotics technology that eliminates dead angles in movement when extracting building geometry. Although, such technology con-
3D-SPACE-SCANNING SYSTEM BY ROBOTIC TECHNOLOGY

349

structs detailed 3D maps of indoor geometry, it is difficult to use in ordinary life because of wind blow noise.

2.2. CAPTUREING HUMAN BEHAVIOR

Regarding the interaction between human beings and architecture, several projects (the Media House Project, 2000; Interactive Architecture, 2009) have combined digital technology and architecture. The sensate room (Beilharz, K, 2005) has used a grid of pressure sensitive mats that was previously installed under the floor. It obtained only two-dimensional positions in the room. Matsushima et al. (2007) have developed a new design process that uses motion capture system to capture human behavior in making a new geometry. These projects deviate from real-world situations, since experiments have been conducted in specific rooms and with special facilities, such as optical cameras and markers, each of which is far removed for ordinary life.

Akiyama (2013) has constructed an environment map with and autonomous mobile robot to solve the human avoidance task. This Project uses "Xtion PRO LIVE" (Xtion) to operate similarly to Microsoft Kinect, which is one of the capturing devices for tracking human behavior.

3. Preliminary study of scanning system

This section describes the fundamental scanning method to extract a building geometry with Xtion. It provides color image data (RGB data), depth data in each pixel, and human bone data (coordinate data of joints) at a low cost. The data of human behavior are detached from the background by the threshold value of the depth data. It is possible to provide simultaneously multiple person tracking data. In this case, a maximum of eight people were captured simultaneously by Xtion. The number depends on the capabilities of software that is Open Ni version 1.5.7.

3.1. ACCURACY OF THE CAPTURING DEVICE

The accuracy of Xtion was confirmed by a preliminary experiment, which measured projection error value (Figure 1). The distance between Xtion and plane of projection was changed every 500mm from 500mm to 5000mm; it was defined the measurable distance of Xtion.

As a result, the error value increased as a secondary curve with distance (Figure 2). Therefore, it is necessary to carefully consider those results when use the capturing data.
3.2. EXTRACTING BUILDING GEOMETRY

Before using the robot, an experiment for scanning building geometry was carried out to find a fundamental parameter; it used Xtion on the 360° rotatable servo motor that rotated every five-degree (Figure 3). The angle and measured point cloud data were sent to computer, and these data integrated with in the CAD. The measurement raw data were analyzed by a computer program that referred to Akiyama’s grid method (2013) and Huang et al.’s voxel grid method. The program runs on Python on Rhinoceros. The process is as follows;

- **Step 1**: A classification of the points of every voxel grid (in this case = 100mm).
- **Step 2**: A count of the number of points included in each voxel is applied to each box size. The box size changes relatively. It shows the probability of the existence of object.
- **Step 3**: A calculation of the shortest distance between the origin point and measured points is applied to each box color. (Result of 3.1 experiments). It shows information of accuracy.
- **Step 4**: Add box in the CAD.

The box size indicates the existence probability, and the box color indicates the authenticity. When the new points or the closer than logged points are generated by the movement of the robot, the data is updated.

According to this method, it is possible to obtain the high accuracy architectural geometry by updating the data. Eventually, the data proves the high accuracy of building geometry, which is filled with green color boxes of maximum sizes.
Figure 3. The result displayed on the CAD.
4. Robot development project

4.1. Advantageous Future for Scanning of Building Geometry with Robotics Technology

This project focused on the characteristics of the "two-wheel vehicle" robot, which rotates and tilts on the spot. The robot can move flexibly on two wheels, each of which can spin independently. It can also gather information on local coordinate values and angles of roll, pitch, and yaw by calculating the accumulated number of rotations. In addition, it travels stably as when its body was inclined by the specific techniques of the collaboration member Y. Sago (Figure 5). These features are advantageous for scanning the three-dimensional object data in a space because the number of sensors and dead angles were reduced by the moving robot.

Figure 4. Experiment of human tracking.          Figure 5. Control the incline of a robot's body.

4.2. Human Tracking Technology

This project tested two technologies for tracking human tracing:

- **Xtion**: Xtion is mounted on the robot’s head. It provides local coordinates as point cloud data between human beings and robot or building geometry (Figure 6). The robot recognizes the first tracked user’s neck position as a tracking object.

- **ZPS (Zone Positioning System)**: ZPS is an ultra-sonic sensor location system that has high accuracy in obtaining the absolute three-dimensional coordinates of objects, such as human beings, robots, and furniture, from the tag (Figure 7). Receiving sensors are attached to the ceiling.

These two systems play complementary roles. If the robot loses sight of a human position, ZPS assists it in finding the right human position.
5. Result of design process involving the robot

The data was sent from both ZPS and Xtion to an Agent Program on the robot via the UDP (User Datagram Protocol) (figure 8). Both data were used to control the robot movement and to construct a voxel grid map. The received data was analyzed and displayed on a voxel grid in the CAD program. However, in this experiment was only implemented in static situations because a part of the program for feedback robot’s angles is not yet complete (figure 9).
6. Discussion and Future works

The experiment of Section 3 shows that an infrared camera is adequate for the purpose of extracting building geometry data, since the window shape penetrated through part of the glass (Figure 3). It is advantage point for architectural design because the window is important design elements. The analysis based on a voxel grid involves the concept of authenticity. This method is effective to reduce the calculation time; however, it is necessary to consider the size of the grid in each situation. In Section 4, the system to control movement of robot used Xtion and ZPS as capture devices. The robot can track only one person. If there are several users in the room, we need to a system to change a tracking object or several robots. From the point of view of ordinarily life, it is the advantage that this robot movement noise is probably quieter than the quadrocopter. Both projects used low-cost RGB-Depth camera, conversely, these projects had common problem that require special facilities such as GPS system, motion capture system and ultra-sonic sensor location system to obtain the absolute coordinate in the room.

This paper does not integrate the scanning system and the controlling system of robot yet. The movement of the robot causes the positional deviation when extracting geometry and the robot’s movement will integrate in the future. It is assumed that the ICP and dead reckoning method (Lee. N, 2011) are effective measures for capturing suitable geometry. To use real-time data of human behaviour several components such as responsive dynamic wall or ceiling are developing now (Figure 10, Figure 11). Moreover, there is a possibility of create a new geometry from natural human behaviour (Matsushima et.al., 2008, Di Raimo, 2010). In addition, this paper suggests that network skill is quite important in connecting architecture and surrounding environments. It is applied not only to the robot but also to various sensors and various actuators.

![Figure 10. Responsive wall unit.](image1)  ![Figure 11. Responsive ceiling unit.](image2)
7. Conclusion

In this paper, the 3D scanning method with robotics technology was proposed through preliminary experiments. As a result, the robot was able to provide building geometry data as point cloud data via the UDP. Furthermore, the human and robot positions were obtained by Xtion and ZPS. However, these processes did not integrate in this paper.

This method allows for an interactive relationship among a human being, a robot, and architecture in the architectural design process. In consequence, it raises the possibility that human behavior would reflect the architectural design in the future.

Acknowledgements

We are particularly grateful for the technical assistance given by Dr. Ryo Saegusa, Yukinori Sago, Kenta Itokazu, Keisuke Shigematsu, the System and Control Laboratory, Department of Mechanical Engineering, and. also thank members of Center for Human-Robot Symbiosis Research, Toyohashi University of Technology. We also thank Kohei Yamazaki, Keisuke Yoshida and Mr. Tsukasa Takenaka for their valuable advices.

References


